# Long-Term Utility of Replanted Arms

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S PORADIC REPORTS of over 50 replanted limbs, or parts of limbs, 2.4-6.11,12.15-18.20,22.24,25,28-32,34,35,37-41 have not resolved the dilemma of whether replantation is only a technical exercise, whether it is actually a liability to the patient, or whether the restoration confers benefits that no other form of therapy can. The results of five successful replantations—the longest followed for 10 years—have now convinced us of the value of a replanted limb under carefully selected circumstances. The uncomplicated convalescences of two patients in whom replantations failed suggest that an attempt at replantation may be justified even if the circumstances are not ideal, provided that an unsuccessful outcome is promptly reconverted into an amputation.

### Case Reports

Case 1. The details of replanting the right (major) arm of a 12-year-old-boy on May 23, 1962, after an ischemic period of about 4 hours have been published.<sup>24</sup> At the time of that report, 11 months after direct neurorraphy of the median and ulnar nerves, muscular activity was beginning to return to the long flexors and to some of the intrinsic muscles of the hand; protective sensation was present. Weak contraction of the biceps was mediated through a 4-cm. graft of a brachial cutaneous nerve into the musculocutaneous nerve, but the radial nerve appeared to have been irreparably damaged by the accident.<sup>33</sup>

Thereafter, to provide active flexion of the shoulder and elbow a tendon transfer was performed in August, 1964; the insertion of the extensor carpi radialis longus was released, and the tendon was transposed to the upper arm, where it was joined to the pectoralis major. The wrist was fused in June, 1965, and at that time the Küntscher nail inserted during the replantation was removed. One month later the patient tore the right medial meniscus and broke the replanted humerus at the site of the initial fracture, but the refracture healed rapidly. In July, 1966, an effort was made to supply extension of the metacarpophalangeal joints of the fingers and extension and abduction of the thumb by transfers of the flexor carpi ulnaris to the common extensors of the second, third,

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fourth, and fifth digits and of the palmaris longus to the extensor pollicis longus and abductor pollicis longus. Because the independent functions of these tendons could not be activated discretely, the objective of the operation was not realized.

By May, 1970, the patient was working 16 hours daily at two jobs. His abilities to manipulate tools and to lift 30-lb. weights to chest level were indispensible to his job as a mechanic, and his callused right palm disclosed the intensity of use. During the next 2 years the patient became successful in a partnership for preparing stock cars for competition and had himself won several dragraces. Then, as before, he was happy with the replanted arm.

Examination showed shortening of the arm and forearm and an increased carrying angle. Power grasp (Fig. 1) was virtually equal to the examiner's. Strength of the opponens pollicis and of the hypothenar muscles was fair. Sensation to pain and touch was good. Two-point discrimination was 1.5 to 2.0 cm. over all fingers; there were a few areas with 1.0-cm. discrimination. Roentgenograms disclosed degenerative disease of the shoulder and elbow joints and osteoporosis throughout the replanted limb (Fig. 2).

Case 2. This 44-year-old machinist died of an unrelated cause 19 months after the replantation of his right (major) arm just above the elbow in an operation (September 5, 1963) that restored blood flow after about 5 hours of ischemia and joined the nerves primarily.<sup>24</sup> The nonunited fracture of his humerus was stabilized with a Küntscher nail, Parham band, and bone grafts in July, 1964, and the extensor carpi radialis longus was transferred to the biceps in October, 1964. Between operations, the patient was working in a shipping room.

Shortly before death, gross protective sensation was present in the distribution of the median nerve in the hand, and there was a little radial sensory component as well. Postmortem dissection of the nerves revealed large neuromas.

Case 3. A 27-year-old carpenter put his left (minor) hand, severed by a circular saw on February 17, 1967, into his apron and sought help (Fig. 3). The distal row of carpal bones and the proximal phalanx of the thumb were fractured.

Cooling of the hand and perfusion of the vessels with cold Ringer's solution were followed by an hour spent in cleaning



Fig. 1. Replanted right arm used in automotive repairing (Case 1).

splinters and devitalized structures from both sides of the amputation. Resection of the proximal row of carpal bones and of the distal ends of the radius and ulna shortened the extremity to allow good cancellous contact for fixation by crossed Kirschner wires.<sup>23</sup>

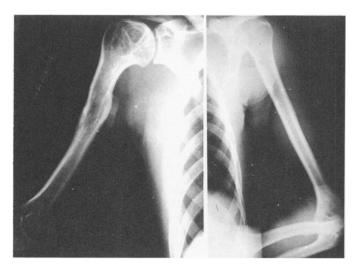


Fig. 2A. Roentgenogram of replanted right arm compared with the left side 10 years after restoration (Case 1).





Fig. 2B. Roentgenogram of replanted forearm compared with the left side 10 years after restoration (Case 1).

Since the amount of blood that would efflux from the veins after arterial reconstruction was predicted to be small, the arteries were rejointed first. After the radial artery with its widely torn intima was pulled from the intrinsic muscles and anastomosed



Fig. 2C. Roentgenogram of replanted hand compared with the left side 10 years after restoration (Case 1).



Fig. 3. Amputated hand (Case 3).

with 6–0 Teflon-coated Dacron under  $2 \times$  magnification, inflow was poor. When the distal end of the ulnar artery was recovered from among the intrinsics and joined, inflow was brisk, and the loss of blood through the veins became difficult to control. Two turgid veins were repaired.

Following restoration of circulation after 5 hours of ischemia, the common extensor tendons were sutured en masse. The injured distal end of the flexor pollicis longus tendon was excised. To provide abduction of the thumb the motor of the flexor pollicis longus was sutured to the stump of the abductor pollicis longus and extensor pollicis brevis. Fusion of the wrist in extension made repair of the wrist extensors unnecessary. To decrease the mass of tissue in the carpal tunnel, a portion of the sublimus tendons was resected. The ends of the median nerve were tagged, and the ends of the ulnar nerve were approximated. Skin coverage was completed by small skin grafts to the dorsum and base of the thumb on the fourth postoperative day. The patient was discharged 17 days after his injury.

During neurolysis in June, 1967, the ulnar pulse in the hand could be seen and felt. There were large neuromas in the ulnar nerve, of which only the deep palmar branch appeared to be preserved; neuromas involved nearly 2 cm. of each end of the median nerve. Following grafting of sublimus tendons into gaps in the profundus tendons, the larger proximal end of the resected ulnar nerve was joined to the smaller distal end with 6-0 Nylon, and the matching ends of the median nerve were repaired similarly.

Good thenar bulk and sensitivity to temperature and pain were noted in December, 1967, when the patient left his carpentry to return for tenolysis. During the following year fusions of the interphalangeal and metacarpophalangeal joints of the thumb and of the distal interphalangeal joints of the middle and ring fingers were performed. In September, 1969, the flexor pollicis longus was transferred to the base of the metacarpal of the thumb. Later, an osteochondroma was removed from the first metacarpal.

Five years after injury the patient was employed full time in outdoor carpentry, where temperatures were occasionally  $-25^{\circ}$ C (Fig. 4). His callused hand had excellent sensitivity to touch and pain and crude two-point discrimination. Although his power grasp could not be fully closed, the patient felt that he was only a little handicapped in his work and demonstrated his ability to lift heavy furniture with his replanted hand. In his words, "I never had it so good since I had it so bad."

Case 4. The right (major) hand of a 5-year-old son of a physician was avulsed at the wrist in an escalator on December 18, 1967. During perfusion of the arteries with Ringer's solution, the effluent from the veins was scanty. Meticulous cleansing of the parts, resection of the proximal metacarpals, and attachment of the hand with crossed Kirschner wires was followed by anastomoses of severely damaged arteries and veins.

When after 14 hours the circulation seemed to be inadequate, the hand was reamputated. The boy was discharged on the sixteenth day. With his hook prosthesis he actively competes with his companions in school; he is glad that an attempt at replantation was made.

Case 5. On January 16, 1969, a 60-year-old machinist was was brought here with his left (minor) hand severed through the wrist by an industrial paper cutter (Fig. 5). The right hand had partial amputation of the index, middle, and ring fingers. Since there was bilateral damage and since the patient seemed unlikely to use a prosthesis, replantation was elected.

The proximal carpal row was resected after the hand was iced and perfused with saline solution. Union to the cancellous surface of the radius was achieved with the aid of crossed Kirschner wires. One vein, both arteries, and a second vein were microsurgically anastomosed with interrupted 7-0 silk after 8 hours of ischemia. Available soft tissue was closed, and the wound was left to drain into a bulky wet dressing. The amputations of the right hand were revised.

Five days later skin grafts were used to close the site of replantation. After a further 13 days the site was re-opened for ex-

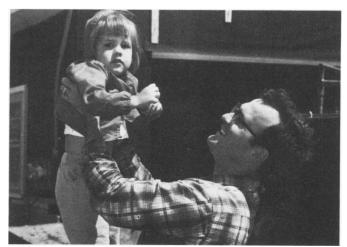


Fig. 4. Replanted left hand (Case 3). A house being built by this carpenter is in the background.



Fig. 5. Amputated hand (Case 5).

cision of the sublimis tendons and for repair of the flexor pollicis longus and of four profundus tendons; the median and ulnar nerves were loosely joined. Discharge was on the fiftieth hospital day.

When flexor tenolysis was done in April, 1969, the first stage of a pedicle nerve graft was done, microsurgically anastomosing the ulnar and median nerves for use later in bridging a gap in the median nerve. At the second stage in October, 1969, 12 cm. of the ulnar nerve was swung down to bridge the defect in the median nerve in the palm. Sensation began to return without delay, and protective sensation appeared in the finger tips and thumb 11 months later. In May, 1970, the common extensor tendons of the fingers and the extensor pollicis longus were repaired with tendon grafts; an arthrodesis of the distal joint of the thumb was carried out in July, 1971.

Three years after replantation the patient has a comfortable, nonedematous hand subject to discomfort only when unprotected on very cold days. He uses his hand for heavy household work such as lifting pots and pans from the stove, sweeping and shoveling, as well as for picking up small objects from a flat surface

Case 6. A 24-year-old man suffered a clean amputation with a bookbinder's guillotine at the lower third of his left (minor) forearm on November 7, 1969. Scanty efflux of perfusate was noted. The bones were shortened and repaired with a Sage pin and an AO compression plate. Despite apparently satisfactory unions of the arteries and veins with 7-0 Teflon-coated Dacron about 7 hours after the injury, blood flow gradually diminished and could not be maintained even after several resections and reanastomoses of the vessels. Clotting seemed to start in the hand and propagate proximally.

A closed amputation was done and the patient was discharged on the eleventh postoperative day. Now using a functional hook with an alternative cosmetic hand, the patient is working full time as a bookbinder, doing home-construction work on weekends for a hobby. Hard use has already worn out two hooks.

Angiograms of his amputated hand were made immediately after the operation and also on the next day. On both occasions there was failure to opacify either palmar arch, and early venous filling and the appearance of the digital arteries suggested arterial occlusion (Fig. 6). Pathologic examination showed an old organized thrombus in both arterial arches (Fig. 7). Thrombosis may have occurred during one of the patient's multiple admissions



Fig. 6. Angiogram of hand 16 hours after reamputation (Case 6).

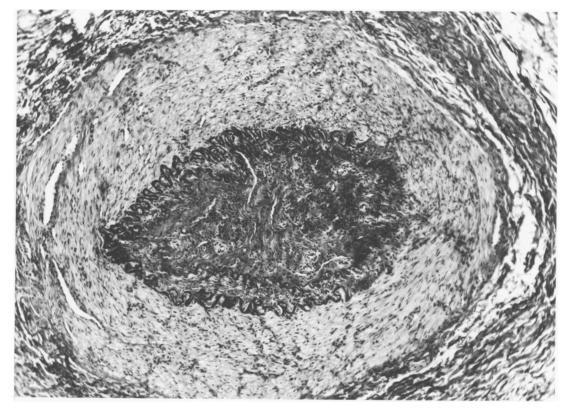


Fig. 7. Occlusive disease of arteries of hand (Case 6). Elastin stain.

to another hospital for correction of a complete harelip and cleft palate.

Case 7. A 28-year-old Spanish-speaking workman suffered an amputation of his left (minor) forearm and several digits in a rubber-processing machine on July 13, 1970 (Fig. 8). Roentgenologic examination showed transection in the distal 7 cm. of the radius and ulna, transection of the thumb and index fingers at the metacarpophalangeal joints, transection of the middle digit at the proximal interphalangeal joint, and loss of soft tissue from the distal third of the ring finger. Because the patient would probably have a difficult time learning to use a prosthesis and because a usable hand seemed to be reconstructable, replantation was elected after the patient, through an interpreter, agreed.

Over 2 cm. of the radius was removed following icing and flushing with saline, and the fractures were reduced over intramedullary Steinman pins. The vascular anastomoses were as in Case 5, and the period of ischemia was 8 hours. The extensor carpi radialis longus and flexor carpi radialis longus were repaired. Following loose approximation of subcutaneous tissue, the wounds were left to drain into a bulky wet dressing. The amputation site closed secondarily, and skin grafts were applied to the digital stumps. The patient was discharged 5 weeks from entry.

In October, 1970, the flexor pollicis longus was repaired, but because of extensive fibrosis the flexors of the fingers were prepared for grafting. Silicone rods were used to bridge the area of forearm scar; five months later the rods were removed, and fascia lata grafts were placed through the new channels in the forearm. In April 1971, the first stage of a pedicle nerve graft was done, followed 5 months later by use of 10 cm. of the pedicled ulnar nerve to span the gap in the median nerve. Six months after the nerve repair the patient has protective sensation at the level of the metacarpophalangeal crease in the palm and at the base of the amputation sites.

The patient is learning to speak English as a part of his re-

habilitation program, which he is pursuing with vigor along with gainful work in the same factory. Ten months after his replantation he saved several members of his family in an apartment fire, lifting a child through a window and carrying him two stories to the ground.

#### Discussion

#### **Patients**

Considerably more than seven of the 700,000 patients entering our Emergency ward in the past decade have been brought here accompanied by major amputated segments of their arms—perhaps 30 to 40 patients in all; yet, only the seven described here were selected for attempted replantation. (Many others had severe acral injuries that left a single vascular pedicle or one or more nerves intact, but as they do not present the same problems in preservation and rehabilitation, they are not included in this survey.) The patients who were not selected for replantation tended to have extensive mangling remote from the site of amputation, avulsion injuries that snapped the major nerves far proximal, or the possibility of major damage to internal organs. Those accepted were mainly psychologically stable people under 30 years old with no major injury except localized trauma in the involved limb, which was in a good state of preservation and which was anatomically suited for replantation.

We continue to believe that patients who meet these

stringent criteria will do best, for patients 1 and 3 had short hospital stays with no complications and now have the best arms. The pedicle flap to substitute for loss of skin in Case 2 dictated a long initial hospitalization, but almost certainly even this 44-year-old man would have had much benefit from return of grasp and sensation, either as a result of the first operation or, more likely, after a later neurorraphy.

Case 4 seemed to confirm the point that only clean injuries should be chosen, for the crushing injury sustained by that child apparently so destroyed the vasculature that satisfactory circulation could not be restored. But if the stringent criteria were infallible guides, patient 6 should have had an excellent result, since his amputation occurred from a single sharp cut, and indeed, this was by far the easiest replantation from technical aspects. The unsuspected element was the organized thrombosis in the palmar arches and the partial occlusion or spasm in the digital arteries.

The results of Cases 5 and 7 showed that the indications for replantation needed to be more elastic. Three years later the man who was 60 years old at the time of injury (Case 5) has a sensate, reasonably powerful grasp of immeasurable help, especially in view of his contralateral digital losses. Grasp and sensation are likewise beginning to return in patient 7, and despite the number of reconstructive operations that will still be required, a hand more useful than a prosthesis will probably be given to this poorly acculturated man.

Distal damage to the amputated part thus need not contraindicate replantation. After successful union of bones and blood vessels, the problems posed by distal damage become susceptible to traditional reconstructive solutions. If useful function can be foreseen, replantation envisioning later reconstruction should certainly be considered strongly.

Surely part of the good results in these rather extreme cases as in the other successful replantations must be attributed to the psychological soundness of the patients. Insofar as it can be evaluated in the stress of the moment, a stable spirit is mandatory for the patient who would do well.

#### Technical Progress

Both the technics and the unsolved problems of replantation remain much unchanged. In preservation of the amputated part while deliberating whether or not to attempt a replantation, no procedure simpler or more effective than putting the amputated part in crushed ice has been described.<sup>23,24</sup> Either Ringer's solution or saline solution perfusates appear to work equally well, despite advantages demonstrated experimentally in the use of dextran solution to minimize postoperative edema.<sup>26</sup> To our knowledge, human extremities preserved by these



Fig. 8. Amputated hand and fingers (Case 7).

methods have been replanted after a maximum of 18 hours of total ischemia,<sup>34</sup> but the limit has not yet been tested. Measurement of intramuscular pH as a guide to irreversible injury may come to be a useful prognosticator.<sup>1</sup>

Although angiograms might have helped in the preoperative assessment of our two failures, the good outcome of the five others, which included only one angiography, leads us not to recommend angiography as a preoperative routine. Imperfect vessels may provoke timidity, even though in practice they could carry blood well enough to sustain the part. We tend rather to believe that attention should be paid to the volume of effluent from the veins during arterial perfusion; in both Cases 4 and 6 it was scanty, and perhaps poor efflux is a sign that should dictate angiography and reassessment of feasibility.

After the decision has been made that the patient and the severed part are suitable for reunion, the bones are shortened to facilitate vascular and neural anastomoses and shaped in the usual ways to provide maximal osseous contact. Although no disturbances of the growth of long bones might be anticipated from the results of experimental replantations, 18 restricted growth of the arm in Case 1 suggests that the situation in human beings might be different; nonetheless, bones should be shortened generously to make replantation possible. The major improvement has been the introduction of AO compression plates for situations in which intramedullary fixation is not optimal, such as fixation of both bones of the forearm. 23

Optical magnification has proved helpful for many vascular anastomoses below the elbow, and true microsurgery has facilitated anastomoses at wrist level.<sup>3,9,19</sup> Interrupted sutures are virtually essential at these levels. If venous return cannot be established, there may be utility in shunting the blood from the replanted member via a Silastic tube into a vein in the other arm<sup>14</sup> and in creating arthrodeses to facilitate intramedullary drainage.<sup>21</sup> Although metabolic acidosis and toxemia when venous return from an ischemic part has been restored have not been recognized in adult human beings, they may occur in children and should be anticipated by serial measurements of arterial pH, gases, and electrolytes and should be treated specifically.<sup>32</sup>

When the skin cannot be closed or when high pressures in fascial compartments during the postoperative stage are predicted, closing the subcutaneous tissue over the repairs and letting the otherwise open wound drain for several days into a bulky wet dressing has worked well. Whether employing this method or not, we have never seen appreciable postoperative edema. Although alert to the need for fasciotomy, we have not had to do it.

The large neuromas found in every patient, attributable perhaps to ischemia as well as to diffuse injury, reinforce our view that repair of nerves should be done secondarily except when a sharp instrument causes a clean amputation and when the period of ischemia is brief. The secondary repair may be done with advantage 3 weeks after injury if the local situation permits. When neural losses have been so severe that the integrity of both the median and ulnar nerves would have to be reconstituted through free isografts, the staged pedicle nerve graft has seemed preferable, sacrificing the ulnar nerve to the median. 33,36 Intrafasicular nerve grafting may ultimately provide even a better alternative.

In the lower limb, in view of the continued poor prognosis for nerve regeneration, of the possibility of painful posterior tibial regeneration syndromes,7 and of the risk of thromboembolism, we doubt that even the demonstrated practicality of replantation has much to recommend it, although several apparently satisfactory results have shown that this point of view may need to be modified by further experience. Excellent prostheses can substitute for the function of the lower limbs in stability and gait. Except if the amputation is too high for a usable prosthesis or if the function of the other lower limb is compromised, the long rehabilitation would seem to be little gain for a doubtful advantage. To the contrary, nerve regeneration in digital replantations of the hand should be excellent, and useful replanted digits have been obtained. For the moment, practicality would seem to dictate attempts at digital replantation principally for multiple amputations or for injuries to the thumb and first fingers.

#### Summary

Five successful and two unsuccessful replantations of the upper limb are reported. Arms useful in complex activities have resulted in two patients at 5 and 10 years, respectively, after replantation. Functional recovery is progressive in two other patients less than 3 years after replantation and was advancing in another patient who died of an unrelated problem 19 months after his restoration. The failures were consequences of extensive crush injuries in one and of arterial occlusive disease in the other.

Replantations are indicated in mentally stable patients without central trauma whose amputated part of the upper extremity is well preserved and whose major acral injuries are limited to the site of amputation. Under these circumstances replantation may be feasible for a patient of any age, despite injuries to the hand itself, especially following amputations at the wrist, and provided that the distal injuries do not interfere with the major circulation.

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#### Discussion

Dr. Robert Arthur Chase (Palo Alto): Dr. Malt and his colleagues excited interest in replantation of the upper extremity in 1962, when they performed the historic procedure listed as Case 1 in today's presentation. It is important that groups with the experience, such as Malt and his colleagues, report the practicality of upper extremity replantation after years of follow-up. I have been involved in the replantation of four upper extremities, and from this experience I agree generally with Dr. Malt's conclusion that there is a valid place for replantation of the upper extremity in carefully selected patients. It is this selection that ultimately may determine whether the procedure is a triumph of technic over reason or a justifiable contribution to the rehabilitation of a patient.

Among the important factors involved in the choice of whether to amputate or attempt replantation is (1) the age of the patient.

The younger the patient, the more likely will be a successful functional regeneration of peripheral nerves from primary repair, secondary repair, or nerve grafting. The importance of age in the patient represented as Case 1 should not be underestimated.

(2) The level of amputation: The more peripheral the replant technically is achieved, the better the ultimate result for a patient of given age. Let me show one instance of an amputation a little bit more peripheral than those shown by Dr. Malt.

(Slide) This is a patient who lost his extremity through the hand from a chain saw. It was replanted by microvascular technics, and out of it came salvage of the very important thumb and index digits.

When it can technically be done, the functional result will be successful, because there is no denervation of proximal musculature, and the patient is likely to gain substantial motor function.

(3) The localization of the injury, as mentioned by Dr. Malt: